The C/O Ratio and Peak Luminosity Variations in SNe Ia

Röpke & Hillebrandt – astro-ph/0403509

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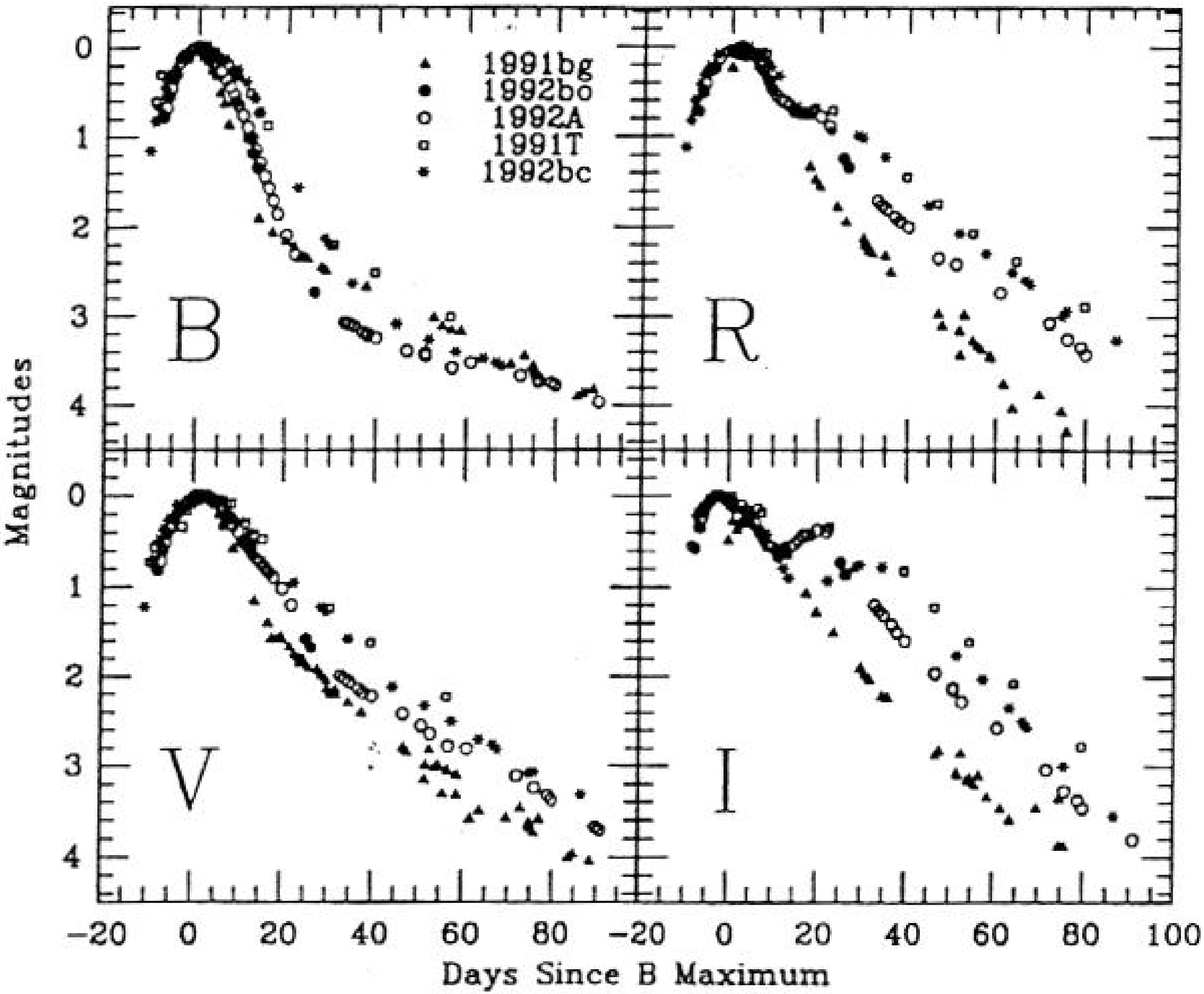
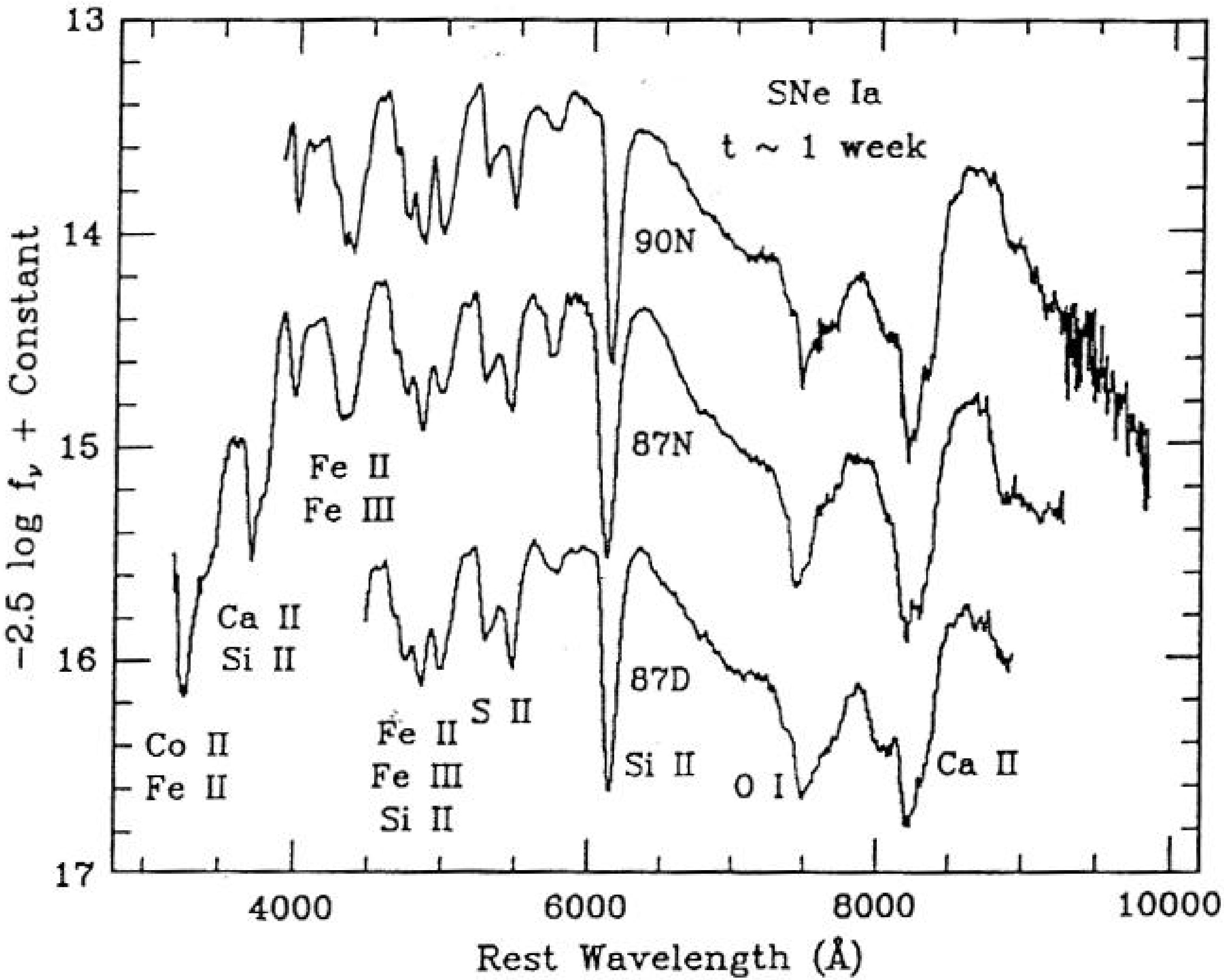
Talk Outline

- How are these models evaluated?
- Historical review.
- More recent historical review.
- Collect vocabulary terms.
- About this paper.

Observables – Lightcurves



Observables – Spectra



Composition Models

The SN theory community consists of two sometimes overlapping groups.

- **Explosion Modellers**
  1. Specify an initial stellar model, blow it up!
  2. Follow nuclear reactions, neutrinos, hydrodynamics.
  3. End up with a **composition model**.
- People: A. Khokhlov, W. Hillebrandt, S. Woosley, P. Höflich, K. Nomoto, D. Arnett, E. Livne...
- Places: NRL, ASCI/Flash, MPA, Santa Cruz, various and sundry national labs.
- Codes: `Flash`, `Prometheus`, others...

Emergent Spectra & Lightcurves

The SN theory community consists of two sometimes overlapping groups.

- **Radiation Modellers**
  1. Obtain or specify a composition model.
  2. Somehow solve the non-equilibrium, time dependent model atmospheres problem. Or not!
  3. End up with an **emergent spectrum**.
- People: D. Branch, E. Baron, P. Nugent, P. Höflich, P. Mazzali...
- Places: OU, LBL, Texas, MPA...
- Codes: `Phoenix`, `Synow`, Lucy/Mazzali MC code.

Burning Regime One

Detonation

- Flame propagates faster than sound crossing time in a fixed volume – **supersonic**.
- If ignition occurs in the center, outer layers of WD never know what hit them.
- WD never gets to readjust (expand) structure, so density stays high during burning.
- At high density, burning proceeds to the peak of the binding energy per nucleon curve and you get Fe-peak.

$\Rightarrow$ **No Intermediate Mass Elements**

Burning Regime Two

Deflagration

- Flame propagates slower than sound crossing time in a fixed volume – **subsonic**.
- If ignition occurs in the center, WD may expand somewhat during burning.
- Burning front encounters lower density stuff above, at densities where the flame converts the C/O into Mg, Si, S, Ca but not so much Fe-peak.
- If the front proceeds slow enough, burning may quench if density drops below some threshold.

$\Rightarrow$ **Fe-peak Surrounded by Intermediate Mass Elements, Perhaps C/O Sitting on Top**

Other Kinds of Burning

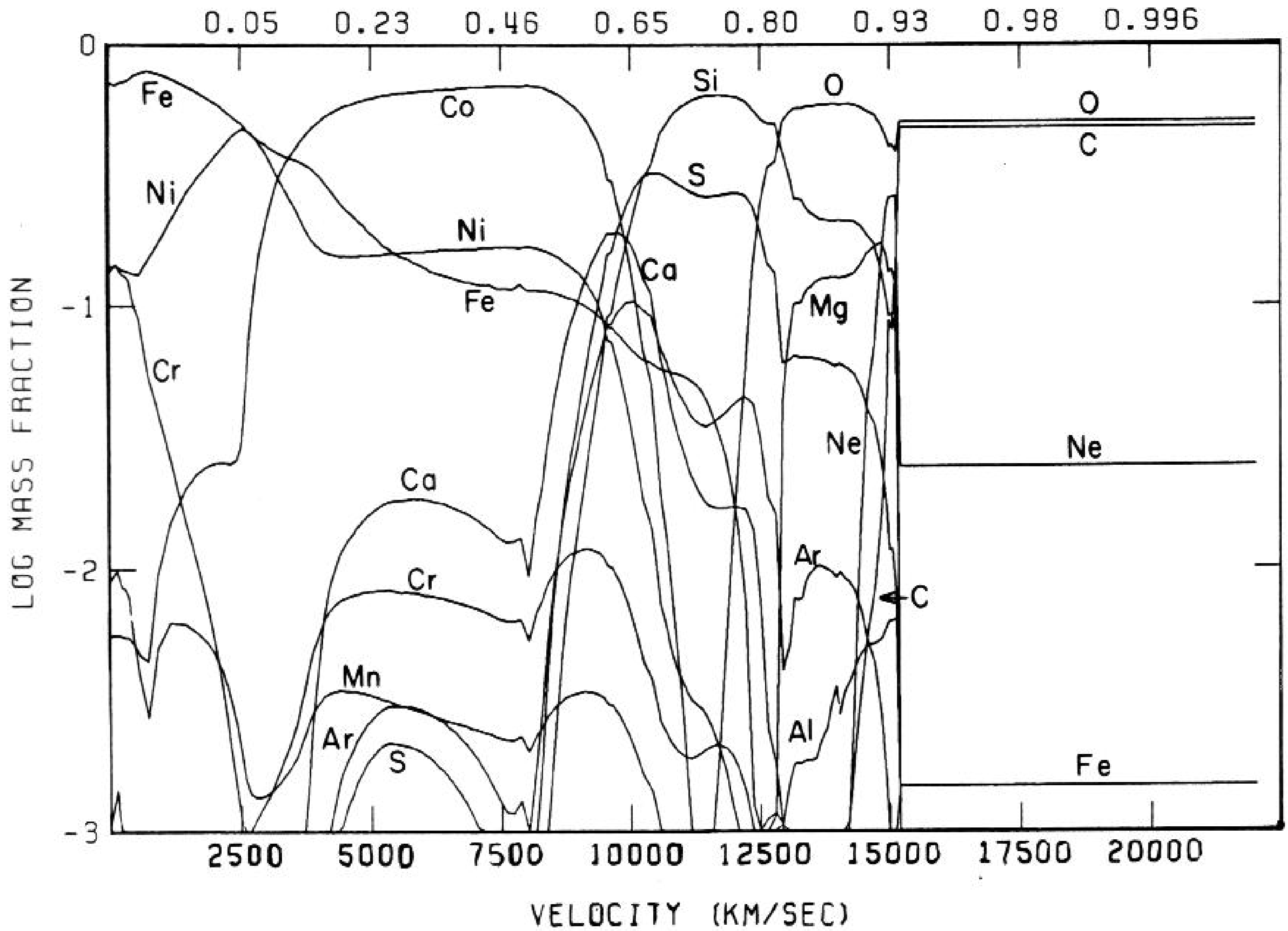
There are combinations of the two.

- Deflagration-to-detonation transition (DDT) – lower the density by deflagration and then start the detonation... somehow.
- Pulsating delayed detonation (PDD) – multiple explosions.
- Off-center detonations.

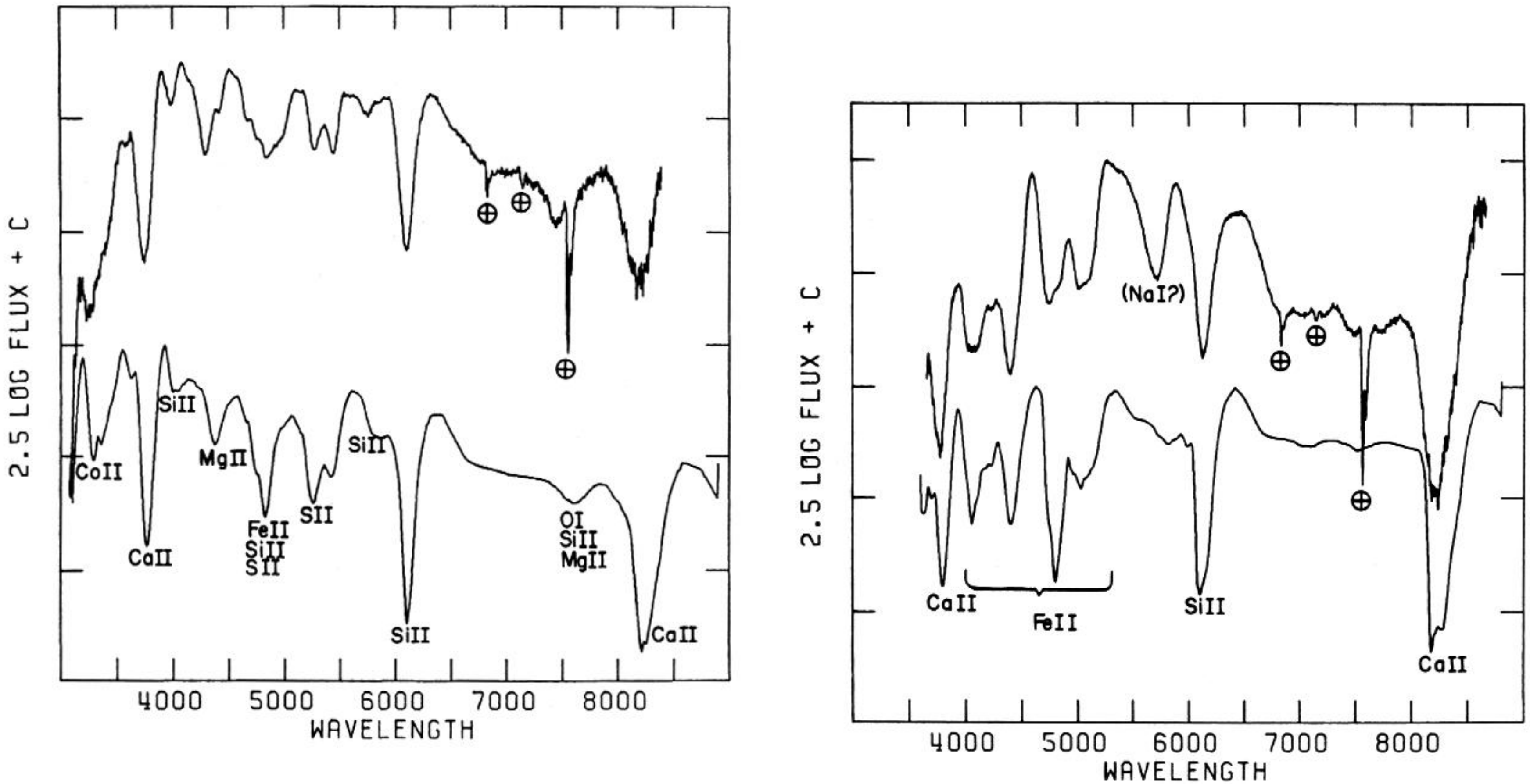
Gold Standard 1D Model, W7

- Start with 1 $M_\odot$ with X(C, O, Ne) = (0.475, 0.5, 0.025).
- Cool for 5.8×10^8 years, then add H at $4 \times 10^{-8} M_\odot$ yr^{-1}.
- Convert it to He via weak (!) shell flashes.
- When central density is 2.6×10^9 g cm^{-3}, ignition.
- Mass is about 1.38 $M_\odot$ at ignition.
- High degeneracy, so the ignition runs away.
- Initially slow, then faster (0.08 to 0.30 times local c_s).
- 0.8 $M_\odot$ Fe-peak, (0.58 $M_\odot$ ^{56}Ni) up to 10000 km s^{-1}.
- 0.5 $M_\odot$ of IME from O through Ca produced and ejected between 10000 and 15000 km s^{-1}.
- 0.1 $M_\odot$ or less of unburned stuff on top.
- Final KE = 1.3×10^{51} erg.

Deflagration Model W7

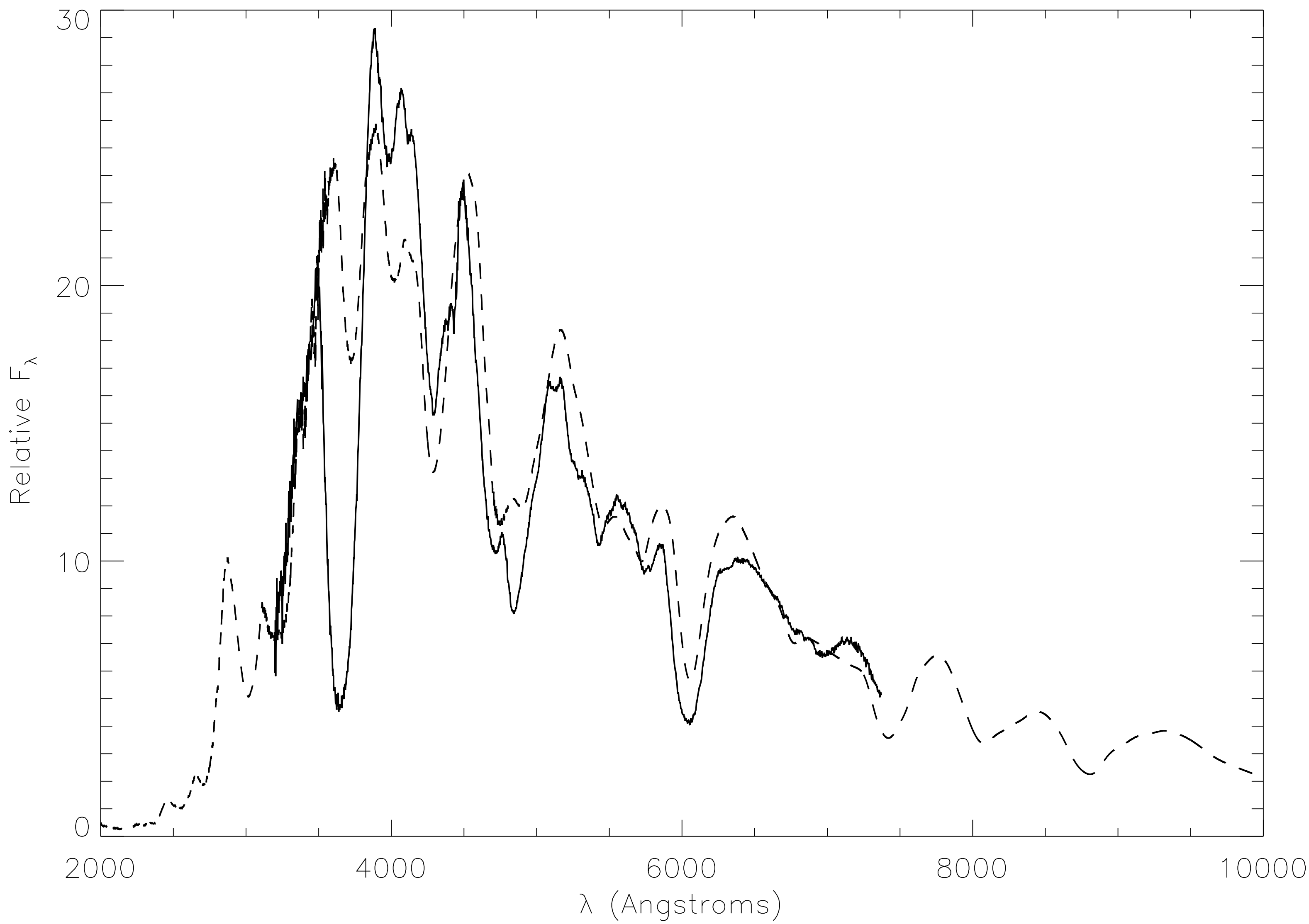


Synthetic Spectra



Without mixing, W7 is not consistent with observations. But Mixing above about 8000 km s^{-1} improved the fits.

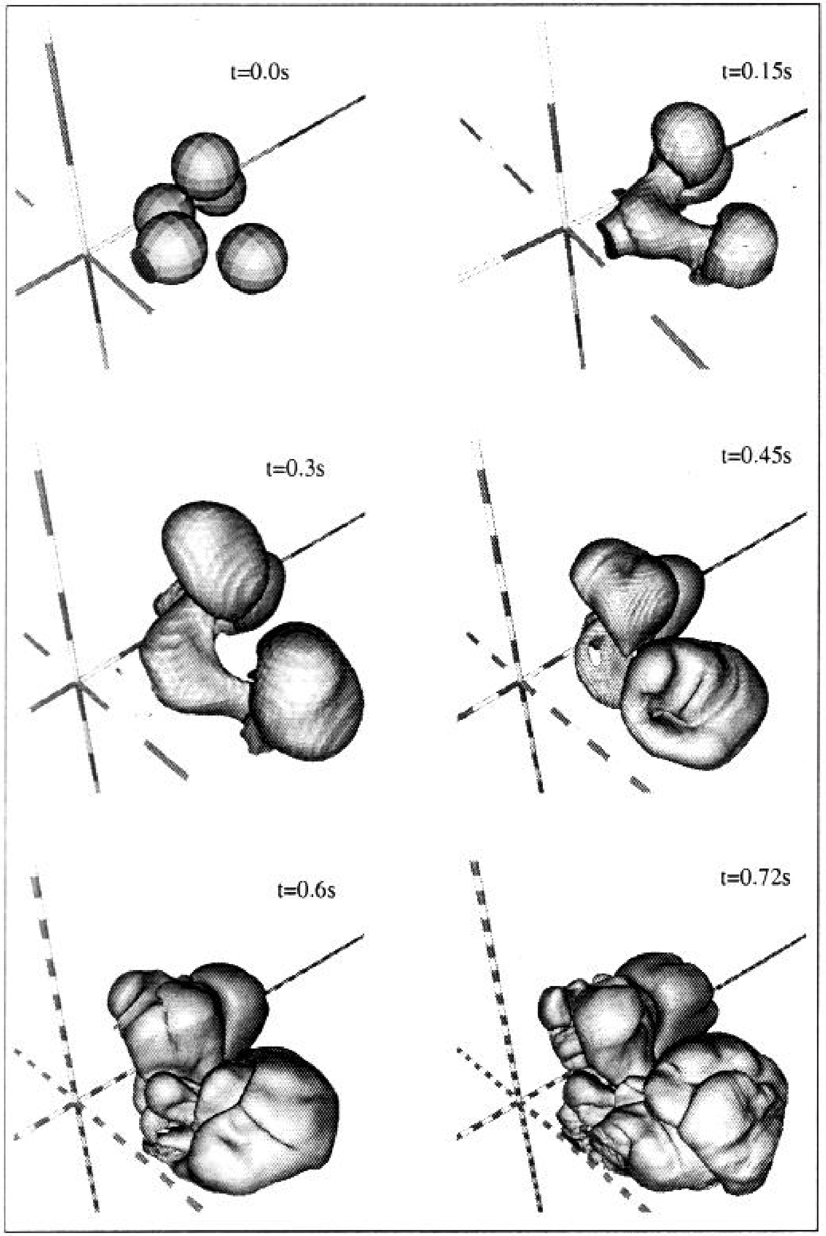
Synthetic Spectra

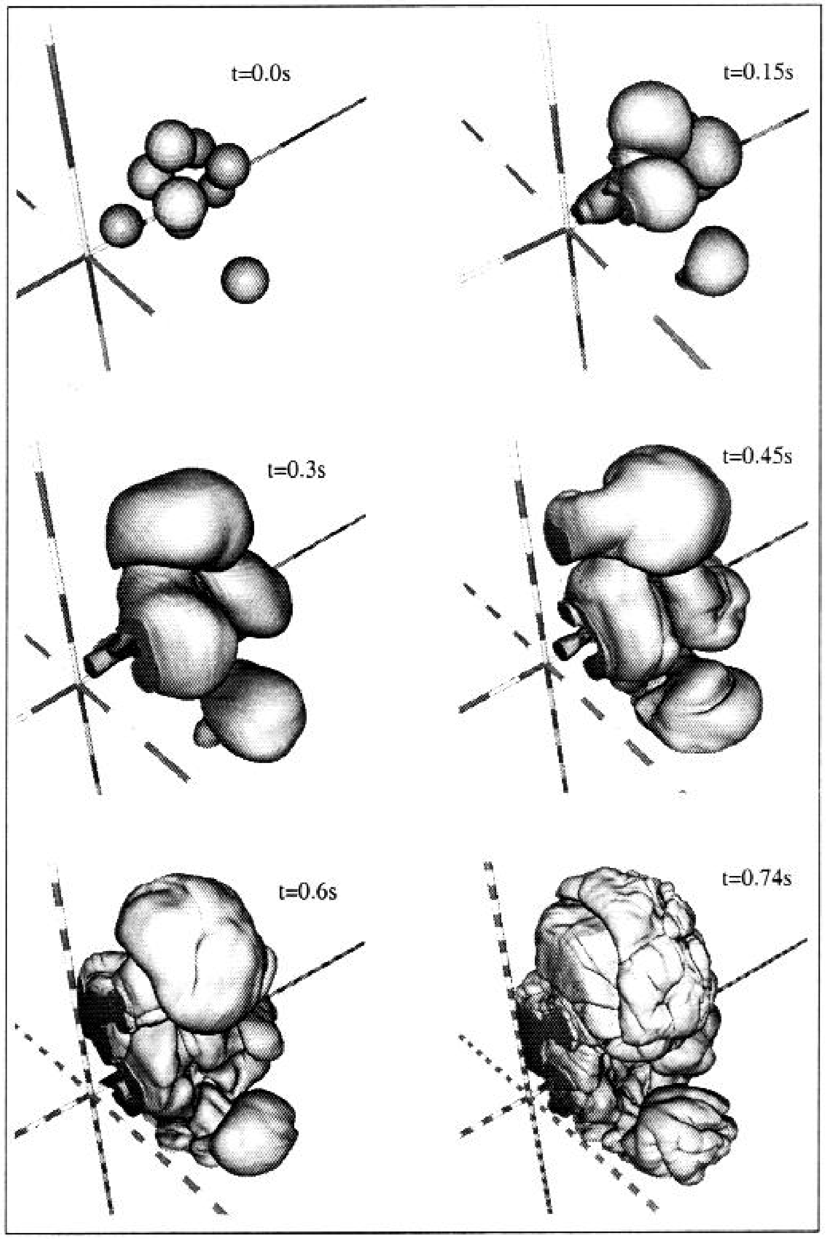


But the Universe is 3D

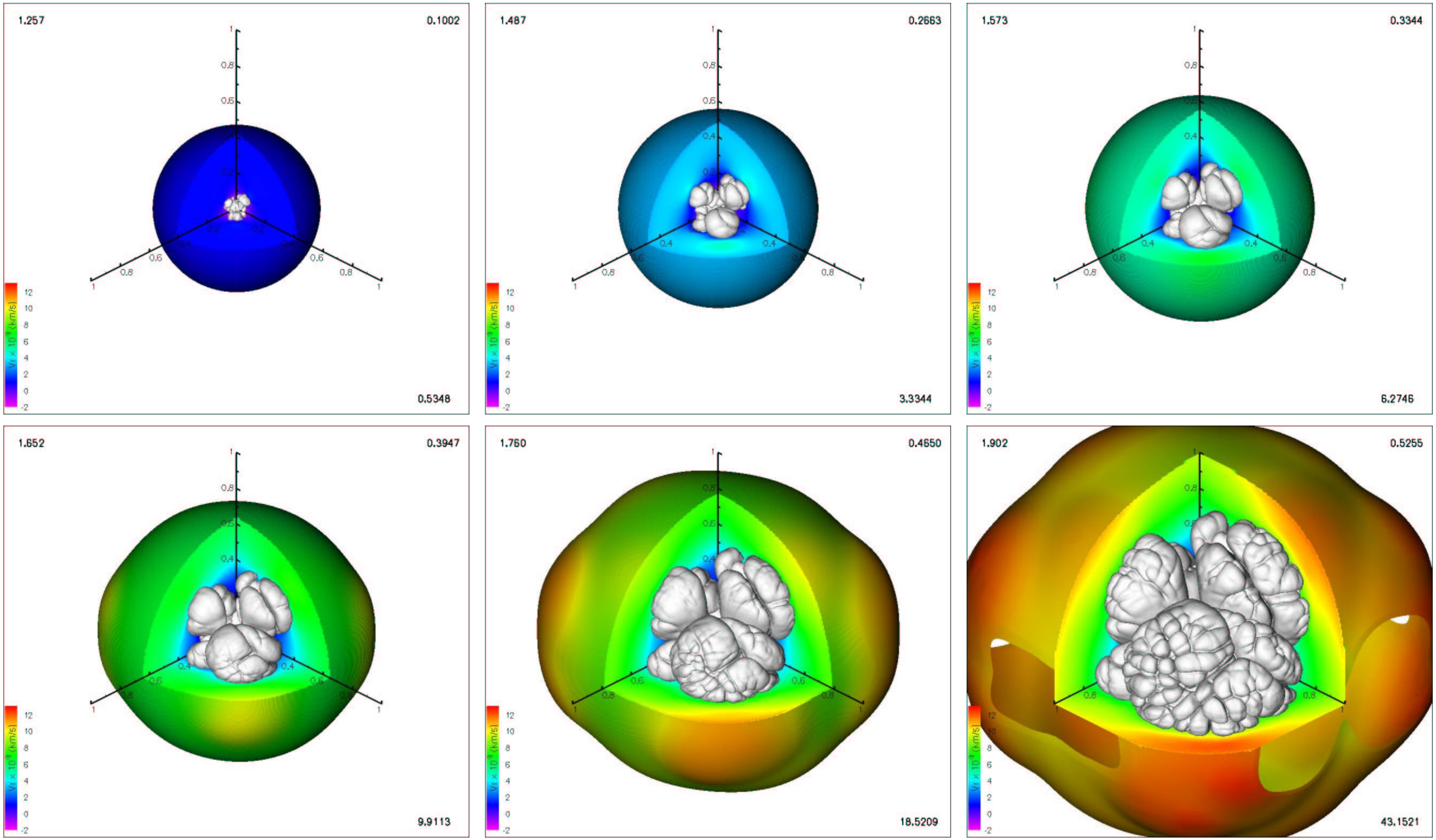
- Spherically symmetric models cannot include all the physics.
- The flame surface is not spherical, it is fractal.
- But the physics is hard!
- Scaling! Flame surface is 0.001 cm thick, and the WD is about 10^8 cm in radius: at least 11 orders of magnitude.
- And it's 3D! Track flame, do nuclear physics, basically eat computer memory.
  - Hillebrandt: Level set technique, fixed grid sizes that expand with the WD.
  - Khokhlov: Fully threaded tree, adaptive mesh refinement.
  - Nuclear physics? Please: fuel/ashes.

3D Deflagration – Reinecke





3D Deflagration – Gamezo



How Well Do the Models Do?

- Both sets of models have energy problems.
  - W7 produces 1 foe when binding energy is accounted for.
  - These models only produce about 0.8, 0.9 foe, **without accounting for binding energy**.
  - That's missing half a foe!
  - Hillebrandt et al: Let us get the resolution up.
  - Khokhlov: 4x effective resolution, still won't get you there.
- Pathological feature of these models:
  - Fuel and ashes are mixed at all radii, contrast to W7.
  - But is it a big deal? Eddie published `Phoenix` (1D!) results and said not really. Perhaps at nebular phase.

This Paper I.

- Nobody understands the Phillips relation? Isn't this reasonable?
  - More Fe-peak $\Rightarrow$ more opacity & energy $\Rightarrow$ longer diffusion time for radiation $\Rightarrow$ broader, brighter lightcurves.
  - Less Fe-peak $\Rightarrow$ not as much opacity & energy $\Rightarrow$ shorter diffusion time for radiation $\Rightarrow$ dimmer, narrower lightcurves.
- Arnett ruled out detonations because they didn't produce IME's in 1969?
  - That would be something, considering they didn't know IME's were there!
  - Instead Arnett just said that detonations don't make IME's.

This Paper II.

- One requirement of any complete model is a “knob” to give you variations in peak magnitude.
- But do they use an immature model?
- Vary the initial C/O ratio a bit.
- Note that the (inadequate?) Ni mass doesn’t really vary with C/O ratio.
- Following Arnett’s Law, luminosity and Ni mass are correlated, so varying C/O, according to RH, does not vary peak luminosity.

What do we conclude? Should we withhold judgment until the resolutions are improved in an effort to get the energy right?

Another More Promising Knob?

- Timmes et al. 2003 ApJ 590, L83, analytical models.
- ^{56}Ni mass produced depends *linearly* on the original metallicity of the WD progenitor 25% variation in mass!